Claims

1. A gallium nitride-based compound semiconductor device comprising:

a substrate;

a first superlattice layer which is formed above the substrate and in which an n-type AlGaN layer and an n-type GaN layer are alternately layered;

a multiple quantum well layer which is formed above the first superlattice layer and in which a GaN-based quantum well layer and a GaN-based quantum barrier layer are alternately layered; and

a second superlattice layer which is formed above the multiple quantum well layer and in which a p-type AlGaN layer and a p-type GaN layer are alternately layered.

2. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

a buffer layer, a first GaN-based layer which is formed above the buffer layer, and an n-type GaN-based layer which is formed above the first GaN-based layer are provided between the substrate and the first superlattice layer;

a second GaN-based layer is provided between the first superlattice layer and the multiple quantum well layer; and

a p-type GaN layer is provided above the second superlattice layer.

3. A gallium nitride-based compound semiconductor device according to Claim 2, wherein

the first GaN-based layer has a structure in which an SiN layer is inserted in a GaN layer, and

the second GaN-based layer has an AlGaN layer.

4. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

a compositional ratio of Al in the GaN-based quantum barrier layer in the multiple quantum well layer is larger than compositional ratios of Al in the first superlattice layer and the second superlattice layer.

5. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

each of compositional ratios of Al in the AlGaN layers in the first superlattice layer and in the second superlattice layer is 5% or greater and 25% or smaller;

a compositional ratio of In in the InGaN quantum well layer or the AlInGaN quantum well layer in the multiple quantum well layer is 3% or greater and 20% or smaller;

a compositional ratio of Al in the AlGaN quantum barrier layer or the AlInGaN quantum barrier layer in the multiple quantum well layer is 1% or greater and 30% or smaller; and

a band gap of the quantum well layer is smaller than a band gap of the quantum barrier layer.

6. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

each of thicknesses of the AlGaN layer and the GaN layer in the first superlattice layer is 1 nm or greater and 10 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum

well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the AlGaN layer in the second superlattice layer is 0.5 nm or greater and 10 nm or smaller; and

a thickness of the GaN layer in the second super lattice layer is 0.5 nm or greater and 5 nm or smaller.

7. A gallium nitride-based compound semiconductor device according to Claim 2, wherein

a thickness of the first GaN-based layer is 500 nm or greater and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 500 nm or greater and 10000 nm or smaller;

each of thicknesses of the AlGaN layer and the GaN layer in the first superlattice layer is 1 nm or greater and 10 nm or smaller;

a thickness of the second GaN-based layer is 5 nm or greater and 100 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the AlGaN layer in the second superlattice layer is 0.5 nm or greater and 10 nm or smaller;

a thickness of the GaN layer in the second superlattice layer is 0.5 nm or greater and 5 nm or smaller; and

a thickness of the p-type GaN-based layer is 5 nm or greater and 50 nm or smaller.

8. A gallium nitride-based compound semiconductor device according to Claim 1, wherein

each of thicknesses of the AlGaN layer and the GaN layer in the first superlattice layer is 1.5 nm or greater and 5 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the AlGaN layer in the second superlattice layer is 1 nm or greater and 6 nm or smaller, and

a thickness of the GaN layer in the second superlattice layer is 0.5 nm or greater and 3 nm or smaller.

9. A gallium nitride-based compound semiconductor device according to Claim 2, wherein

a thickness of the first GaN-based layer is 1500 nm or greater and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 1000 nm or greater and 2000 nm or smaller;

each of thicknesses of the AlGaN layer and the GaN layer in the first superlattice layer is 1.5 nm or greater and 5 nm or smaller;

a thickness of the second GaN-based layer is 20 nm or greater and 40 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the AlGaN layer in the second superlattice layer is 1 nm or greater and 6 nm or smaller;

a thickness of the GaN layer in the second superlattice layer is 0.5 nm or greater and 3 nm or smaller; and

a thickness of the p-type GaN-based layer is 10 nm or greater and 40 nm or smaller.

10. A gallium nitride-based compound semiconductor device comprising:

a substrate;

an n-type AlGaN layer which is formed above the substrate;

a multiple quantum well layer which is formed above the n-type AlGaN layer and in which a GaN-based quantum well layer and a GaN-based quantum barrier layer are alternately layered; and

a p-type AlGaN layer which is formed above the multiple quantum well layer.

11. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a buffer layer, a first GaN-based layer which is formed above the buffer layer, and an n-type GaN-based layer which is formed above the first GaN-based layer are provided between the substrate and the n-type AlGaN layer;

a second GaN-based layer is provided between the n-type AlGaN layer and the multiple quantum well layer; and

a p-type GaN-based layer is provided above the p-type AlGaN layer.

12. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a compositional ratio of Al in the GaN-based quantum barrier layer in the multiple quantum well layer is larger than compositional ratios of Al in the n-type AlGaN layer and the p-type AlGaN layer.

13. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

each of compositional ratios of Al in the n-type AlGaN layer and in the p-type AlGaN layer is 5% or greater and 25% or smaller;

a compositional ratio of In in the InGaN quantum well layer or the AlInGaN quantum well layer in the multiple quantum well layer is 3% or greater and 20% or smaller;

a compositional ratio of Al in the AlInGaN quantum barrier layer or the AlGaN quantum barrier layer in the multiple quantum well layer is 1% or greater and 30% or smaller, and

a band gap of the quantum well layer is smaller than a band gap of the quantum barrier layer.

14. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a thickness of the n-type AlGaN layer is 50 nm or greater and 500 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 2 nm or greater and 50 nm or smaller; and

a thickness of the p-type AlGaN layer is 50 nm or greater and 500 nm or smaller.

15. A gallium nitride-based compound semiconductor device according to Claim 11, wherein

a thickness of the first GaN-based layer is 500 nm or greater and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 500 nm or greater and 10000 nm or smaller;

a thickness of the n-type AlGaN layer is 50 nm or greater and 500 nm or smaller;

a thickness of the second GaN-based layer is 5 nm or greater and 100 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 5 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 2 nm or greater and 50 nm or smaller;

a thickness of the p-type AlGaN layer is 50 nm or greater and 500 nm or smaller; and

a thickness of the p-type GaN-based layer is 5 nm or greater and 50 nm or smaller.

16. A gallium nitride-based compound semiconductor device according to Claim 10, wherein

a thickness of the n-type AlGaN layer is 70 nm or greater and 300 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller; and

a thickness of the p-type AlGaN layer is 70 nm or greater and 200 nm or smaller.

17. A gallium nitride-based compound semiconductor device according to Claim 11, wherein

a thickness of the first GaN-based layer is 1500 nm or greater

and 3000 nm or smaller;

a thickness of the n-type GaN-based layer is 1000 nm or greater and 2000 nm or smaller;

a thickness of the n-type AlGaN layer is 70 nm or greater and 300 nm or smaller;

a thickness of the second GaN-based layer is 20 nm or greater and 40 nm or smaller;

a thickness of the quantum well layer in the multiple quantum well layer is 1 nm or greater and 2 nm or smaller;

a thickness of the quantum barrier layer in the multiple quantum well layer is 6 nm or greater and 20 nm or smaller;

a thickness of the p-type AlGaN layer is 70 nm or greater and 200 nm or smaller; and

a thickness of the p-type GaN-based layer is 10 nm or greater and 40 nm or smaller.

18. A method for manufacturing a gallium nitride-based compound semiconductor device according to Claim 2 through MOCVD, wherein

the buffer layer is formed on the substrate at a temperature of 450 °C or higher and 600 °C or lower;

the first GaN-based layer, the n-type GaN-based layer, and the first superlattice layer are sequentially formed on the buffer layer at a temperature of 1050 °C or higher and 1100 °C or lower;

the second GaN-based layer and the multiple quantum well layer are sequentially formed on the first superlattice layer at a temperature of 800 °C or higher and 900 °C or lower; and

the second superlattice layer and the p-type GaN-based layer are sequentially formed on the multiple quantum well layer at a temperature of 950 °C or higher and 1025 °C or lower.

19. A method for manufacturing a gallium nitride-based compound semiconductor device according to Claim 11 through MOCVD, wherein

the buffer layer is formed on the substrate at a temperature of 450 °C or higher and 600 °C or lower;

the first GaN-based layer, the n-type GaN-based layer, and the n-type AlGaN layer are sequentially formed on the buffer layer at a temperature of 1050 °C or higher and 1100 °C or lower;

the second GaN-based layer and the multiple quantum well layer are sequentially formed on the n-type AlGaN layer at a temperature of 800 °C or higher and 900 °C or lower; and

the p-type AlGaN layer and the p-type GaN-based layer are sequentially formed on the multiple quantum well layer at a temperature of 950 °C or higher and 1025 °C or lower.

20. A gallium nitride-based compound semiconductor device according to any one of Claims 2 through 11, further comprising:

an n electrode which is connected to the n-type GaN-based layer;

a p electrode which is connected to the p-type GaN-based layer; and

a power supply which applies a voltage between the n electrode and the p electrode.

21. A device which uses a gallium nitride-based compound semiconductor device according to Claim 20 as a light source and irradiates light having a wavelength of 400 nm or shorter.